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TECHNICAL REPORT RD-82-11

# MISSILE SYSTEM SIMULATION AT THE ADVANCED SIMULATION CENTER

Systems Simulation and Development Directorate
Advanced Simulation Center
US Army Missile Laboratory



25 January 1982

**U.S. ARMY MISSILE COMMAND**

*Redstone Arsenal, Alabama 35809*





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# REPORT DOCUMENTATION PAGE

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| | | |
|---|---|---|
| 1. REPORT NUMBER<br>TECHNICAL REPORT RD-82-11 | 2. GOVT ACCESSION NO.<br>AD-A147829 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>Missile System Simulation at the Advanced Simulation Center | | 5. TYPE OF REPORT & PERIOD COVERED<br>Technical Report |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>Tech Note 106-009 |
| 7. AUTHOR(s)<br>Dr. M. M. Rea/Dr. A. M. Baird (Analytics, Inc.)<br>F. E. Batchelder (Boeing)<br>F. M. Belrose/W. C. Holt (US Army MICOM) | | 8. CONTRACT OR GRANT NUMBER(s)<br>DAAH01-81-C-B057 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Analytics, Inc.<br>2500 Maryland Road<br>Willow Grove, PA 19090 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Commander, US Army Missile Command<br>ATTN: DRSMI-RPT<br>Redstone Arsenal, AL 35898 | | 12. REPORT DATE<br>25 January 1982 |
| | | 13. NUMBER OF PAGES<br>28 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)<br>Commander, US Army Missile Command<br>ATTN: DRSMI-RD<br>Redstone Arsenal, AL 35898 | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Simulation Objectives
Simulation Benefits
Missile System Simulation
Simulation Philosophy
Simulation Capabilities
Simulation Management
Modeling Philosophy
RF Environmental Models
Verification and Validation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document discusses the objectives and benefits of simulation in developing and fielding missile weapon systems, summarizes the current state of simulation technology as it exists at the Advanced Simulation Center, and presents the ASC RF environmental modeling philosophy, capability, and techniques. The following key simulation elements are developed:

ABSTRACT (Continued)

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1) Simulation realism is achieved by utilizing seeker and guidance electronics hardware in the simulation, 2) Environmental models are crucial in achieving realistic seeker-in-the-loop missile guidance simulations, 3) Models of the proper level of complexity must be selected based upon simulation objectives and seeker sophistication, 4) Verification and validation of both environmental models and the simulation are necessary for confident use of simulation results, 5) Customer participation in defining goals, objectives, and requirements is essential to achieve a successful simulation, 6) A simulation support program should evolve in conjunction with the missile system development program, with complexity being added as required, resulting in a mature simulation with the proper fidelity to support the fielded system, and 7) Key benefits of such a simulation support program encompass both management savings in resources and technical contributions to system understanding and effectiveness.

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# I. SIMULATION OBJECTIVES AND BENEFITS

## A. INTRODUCTION

The development and fielding of high-technology weapons in the current environment of cost-consciousness and reduced acquisition times requires effective test and evaluation support over the entire life cycle of a weapon system. The Advanced Simulation Center (ASC) of the U.S. Army Missile Command, Redstone Arsenal, Alabama, provides this support to the defense community through high-quality simulation services. Current capabilities are oriented toward missile system simulation, while the long-range goal of the center is to simulate the performance of entire weapon systems. When properly integrated into an overall test and evaluation program, these simulations provide a cost-effective source of reliable data which can be used to reduce the risk and uncertainty in system performance, and thus improve management decision-making over the entire missile system life cycle. The ultimate benefit from effective simulation is the knowledge that a quality product has been fielded to successfully meet the intended mission need.

The ASC provides a controlled, realistic environment in which missile seeker hardware is used in conjunction with large-scale analog and digital computers to provide a simulation of the total missile system. These seeker-in-the-loop simulations, when used in conjunction with a compatible flight test program and digital or hybrid simulations, provide the most cost-effective management tool available for missile system development and performance evaluation. In the missile guidance simulations the actual seeker hardware is exercised at its proper operating frequency in realistic engagement scenarios. The models of targets, clutter, countermeasures, and other physical effects, which define the environment of the seeker, are key elements in determining simulation realism and guide the application of simulation results to actual systems.

In this way, the seeker-in-the-loop simulation evaluates critical hardware and software items as well as the simulated components of the missile in realistic, dynamic electromagnetic environments. It increases the value of the flight test program by replicating the flight test scenario in preflight and postflight analyses. In turn, the flight test program is used to validate the seeker-in-the-loop simulation as well as digital or hybrid simulations.

This document provides an overview of the ASC approach to missile system simulation, defines the role of simulation in relation to other methods of system performance evaluation, and presents the potential benefits to be derived from simulation support over the weapon system life cycle. The topics covered include the ASC philosophy and methodology, simulation capabilities, and the ASC management approach. This document

also describes the ASC approach to environmental modeling and the verification and validation program which ensures both model and simulation realism. A summary highlights key points contained in the document.

## B. MISSILE SYSTEM SIMULATION

Defense Department procedures for acquiring and supporting weapon systems establish key milestones at which both programmatic and technical decisions must be made. Recent actions to streamline and shorten the system acquisition process accentuate the need for reliable and timely data upon which to base these decisions. An increasingly important and valuable source of information for decision makers is weapon system simulation, which replicates system operation and the physical effects which influence system performance in a controllable environment. The ASC has been the pioneering facility in providing state-of-the-art technology for non-destructive simulation of missile sensors, guidance and control components, and flight hardware and continues as the technology leader in this field. The facility performs simulations across a wide band of the electromagnetic spectrum, including radio-frequency (RF) systems such as the HAWK air defense missile and the Advanced Medium Range Air-to-Air Missile (AMRAAM), infrared (IR) weapons such as CHAPARRAL and STINGER, and electrooptical (EO) systems such as SPIKE and FOG-D.

Management and technical constraints in developing today's missile systems require that a set of system simulations be established and used in developing and fielding each missile system. Many program development offices in DoD have recognized this requirement and are providing funds at the front end of development programs to establish the appropriate set of simulations as early as possible in the procurement cycle. The management and technical constraints driving the requirement include the following needs:

- improved cost-effectiveness,
- reduced risk and uncertainty,
- convincing system demonstration,
- confident performance evaluation to optimize warhead size and deployment strategies,
- on-schedule deployment, and
- quick response to threat changes.

Ideally, the set of system simulations are established during the technology base or technology transfer phases of each missile system life cycle and are maintained and used throughout system development, production, and

deployment. The simulation set includes digital, hybrid, seeker-in-the-loop, and man-in-the-loop simulations which are used in a balanced mix with other performance evaluation methods.

The simulations selected for a particular system supplement and complement the more traditional tools available for the assessment of weapon system performance. As a result of early guided missiles being tested primarily in the field, flight testing became a mature engineering discipline. However, for both scientific and fiscal reasons, the performance of today's multi-mode, multi-function seeker guided missiles cannot be adequately assessed by flight tests alone. In particular, complex systems performing many functions require testing in a controlled environment to determine response sensitivity to various stimuli. This is essentially impossible in field testing due to factors such as specific terrain features and system-to-system variation. Additionally, the high cost and technical complexity of flight testing today precludes the number of experiments required to exercise an adequate envelope of system parameters to perform statistical data collection, to demonstrate repeatability (an essential factor in system reliability), and to evaluate proof-of-concept. In fact, the reliability, availability, and maintainability (RAM) data acquired during repeated simulation runs is a unique and significant byproduct of seeker-in-the-loop simulation.

## C. SYSTEM PERFORMANCE EVALUATION METHODS

To supplement the knowledge which can be gained from flight tests, a hierarchy of missile performance evaluation methods has evolved; these methods are ordered in terms of increasing realism and complexity in Figure 1. *Combat* is the ultimate measure of system effectiveness. *Guided flight tests* closely emulate reality, although in this method a surrogate environment is typically substituted for an actual threat scenario. Realism vis-a-vis the threat is an issue which must be satisfactorily demonstrated before flight test predictions can be accepted with great confidence.

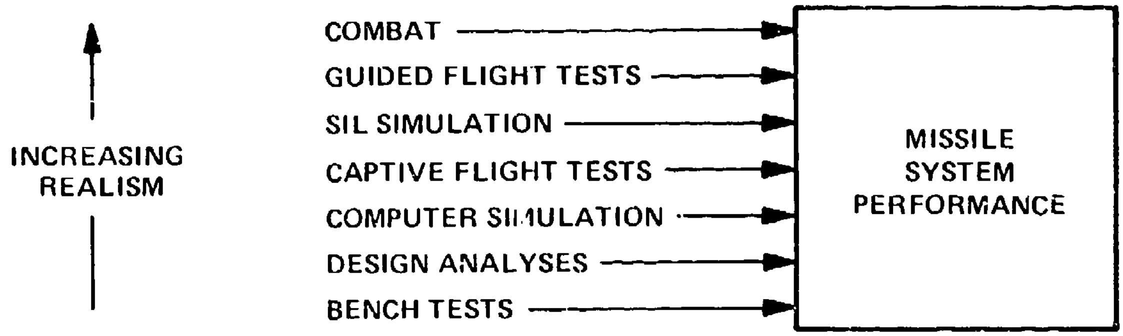


Figure 1. Hierarchy of Performance Evaluation Methods

In the remaining evaluation methods -- seeker-in-the-loop (SIL) simulation, captive flight tests, computer simulation, design analyses, and bench tests -- certain aspects of reality are replaced by models to gain scientific control over engagement scenarios and the large number of variables which can affect missile performance. Each method contributes to the overall understanding of system performance. *Bench tests* provide data regarding the behavior of individual hardware components. *Design analyses* predict the interaction of these subsystems. *Computer simulation* is an analytical tool for predicting overall system performance. *Captive flight tests* evaluate seeker hardware performance in flight but without the correct dynamic effects of motion. *Seeker-in-the-loop simulation* provides a test bed for seeker hardware performance on a three-axis flight table in a controlled electromagnetic environment and includes the additional aspects of flight dynamics through computer models of the missile.

Varying degrees of realism can be achieved within each performance evaluation category. Targets in flight test can range from representative threats to ones with strongly augmented signatures to ensure missile guidance; environmental conditions can range from benign to adverse with severe clutter and countermeasures. Similar degrees of realism can be obtained in seeker-in-the-loop simulations, captive flight tests, and computer simulations. For example, target models utilized in seeker-in-the-loop simulations at the ASC possess signature characteristics such as amplitude scintillation and range and angle glint which are more realistic and threat representative than those of subscale drones often used as targets in flight tests. In simulation as well as in flight tests, it is imperative that the appropriate degree of signature realism and complexity be selected for the questions and scenarios under examination. Realism in performance evaluation generally requires increased complexity, greater cost, and longer development time, whereas *excessive* fidelity wastes valuable resources. On the other hand, inadequate fidelity used to answer tough system questions provides meaningless answers which generally are misapplied.

The performance evaluation methods identified in Figure 1 should not be viewed as independent, but rather as constructively interacting modes contributing to an overall system test program. The controlled environment which can be achieved in laboratory and computer tests provides a valuable tool in both the planning and analysis of flight tests. Flight test data in turn can provide the benchmark against which the realism of simulation predictions can be judged. Similarly, a mature seeker-in-the-loop simulation which has been developed as an integral element of the missile system procurement process can enhance combat performance by providing an operational tool in the development and refinement of battlefield tactics, and a mechanism for quick reaction to changes in threat capabilities or characteristics. The proper role of simulation in the overall mix of performance evaluation methods is the subject of the next subsection.

## D. ROLE OF SIMULATION

Many guided missiles currently in use or in development are sophisticated devices which behave as complex, non-linear mechanisms both in their internal operation and in their electromagnetic interaction with targets, countermeasures, and the natural environment. This is especially true of the intelligent, autonomous acquisition missiles which are being developed because of their tactical superiority. High-fidelity computer simulation of these systems has proven to be too slow, costly, unwieldy, and uncertain to be of practical use as a systems analysis tool. Low-fidelity computer simulation is useful in defining operational constraints, but is too simplified to provide reliable answers to questions involving detailed subsystem interactions. Flight tests are too expensive for large-scale data collection, too overt for countermeasure evaluation, and not readily repeatable. Seeker-in-the-loop simulation technology has been developed at the ASC to augment the capabilities of computer simulation and flight testing and to provide an effective management and engineering tool for the analysis, development, testing, and operational support of missile guidance systems. Seeker-in-the-loop simulation bridges the gap between analyses and flight tests by providing a cost-effective method to fill measurement voids and provide responsive operational support.

Like computer simulation and flight tests, seeker-in-the-loop simulation requires a substantial initial investment in time, money, and manpower. The experience of the ASC has been that each new missile system to be simulated has unique requirements which demand careful planning and adequate development time. The best use of simulation resources is made when simulation capabilities evolve in conjunction with the missile system development process. As illustrated in Figure 2, the simulation is then

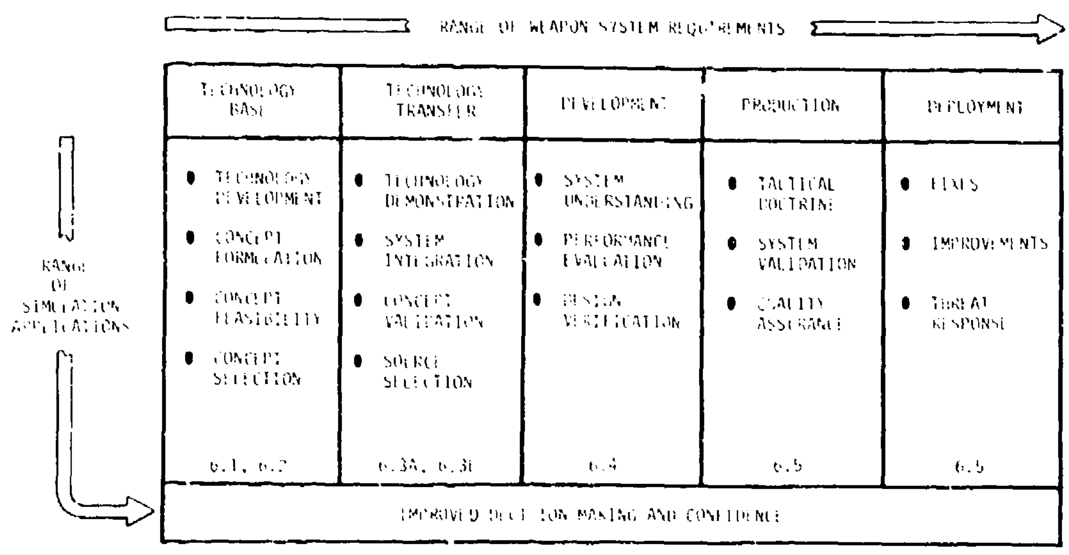


Figure 2. Role of Simulation during the Missile System Life Cycle

available to provide answers to both routine and unanticipated questions which arise during the missile system life cycle. More importantly, as the simulation is validated during the system development process, confidence in simulation predictions increases. A major decision, such as whether or not to enter production, can be based largely upon simulation results only if the simulation provides a demonstrable correspondence to flight tests, i.e., only if it can be validated.

The simulation realism necessary to predict flight test results cannot be achieved instantaneously, nor are the requirements for simulation realism the same throughout the missile system life cycle. During the early development stages, when concept formulation, proof-of-concept, and source selection are dominant issues, relatively simple and straightforward simulation environments are often appropriate. During full-scale development and initial production, when system performance under adverse combat conditions must be demonstrated, much more complex environments are needed. The demonstration of the ability to simulate these complex environments results in a simulation which is available as a tool to measure system performance versus mission needs. Simulation complexity must evolve along with the weapon system and be available to enhance operational effectiveness.

## E. SIMULATION BENEFITS

Historically, simulation has been performed to obtain technical contributions such as system understanding, evaluation, validation, improved quality, and covertness. Simulations are now performed for both technical and managerial reasons. Management benefits are realized as tangible, measurable savings throughout the weapon system life cycle in cost, time, and manpower. As illustrated in Figure 3, the benefits of simulation are realized throughout all phases in the missile system life cycle.

Each of these benefits is discussed below:

- Understanding -- Seeker-in-the-loop simulation provides the ability to examine and measure the performance capabilities and limitations of complex systems by conducting complex experiments in a controlled and repeatable laboratory environment. Data is obtained which is significantly more detailed, complete, and covers a broader range of environments and scenarios than is possible using traditional system test methods. Real-time data analysis capabilities provide a unique opportunity for the simulation team to vary parameters interactively to explore unexpected phenomena.

- Evaluation -- Seeker-in-the-loop simulation at the ASC provides the program manager with a dependable, independent government evaluation tool for his missile system. Complex, non-destructive experiments can be performed which are otherwise impossible or prohibitively expensive. Also, Monte

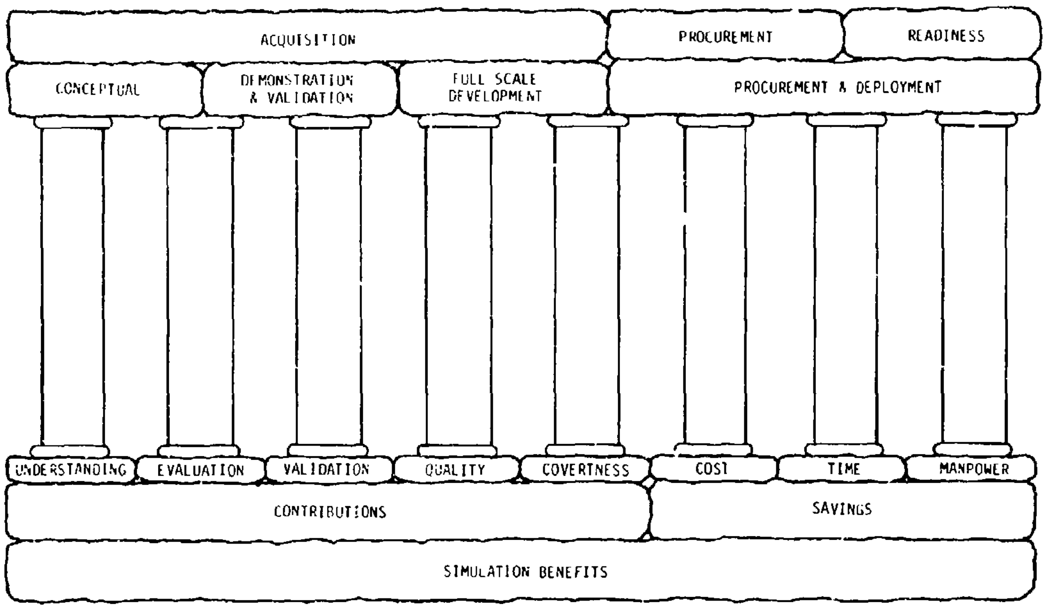


Figure 3. Key Simulation Benefits

Carlo simulation techniques provide realistic values for statistical parameters which are subsequently used by operations analysts to assess system performance.

- Validation -- Seeker-in-the-loop simulation is a unique, powerful method for validating missile performance capability against mission needs. Both developmental and operational tests are performed at all phases of the system life cycle. This results in improved confidence in system performance with an attendant reduction in program risk.

- Quality -- Life cycle simulation support exposes problem areas early in development, allowing early redesign. Performance envelopes are mapped completely and efficiently, resulting in improved tactical doctrine. The simulation customer is provided with a better fielded product because of validated performance in threat environments.

- Covertness -- The controlled emission environment of the ASC allows covert evaluation of foreign systems and jammers as well as development and test of sensitive DoD compartmentalized programs.

- Cost -- Significant reductions in overall program costs are achieved by utilizing seeker-in-the-loop simulation to reduce the number of flight tests. Preflight simulations are used

to select the most important engagement scenarios; system deficiencies are often exposed in advance. Postflight simulations are used to exploit flight test data to its full potential.

- Time -- Initial program development time is reduced by providing extensive testing with limited hardware. Design deficiencies are exposed early in the development cycle. Competitive selection issues are resolved in a common test bed. Quick reaction to changing threat characteristics is provided.

- Manpower -- Both government and contractor manpower is saved as a result of the improved efficiency achieved by eliminating false starts, exposing deficiencies early, and correctly resolving complex technological issues.

In fact, improved quality and conservation of valuable resources are natural byproducts of utilizing seeker-in-the-loop simulation throughout the missile system life cycle. Without simulation, such system goals could be achieved only with substantial increased investment. To ensure a cost-effective program while minimizing risk and uncertainty and building confidence in system performance, program managers should:

- recognize and provide a balanced mix of performance evaluation methods,

- recognize the proper role of simulation,

- invest time and effort in the simulation process,

- investigate the full range of system applications and scenarios with increasing complexity and fidelity, and

- apply simulation throughout the weapon system life cycle.

The following section provides a more detailed discussion of the ASC simulation philosophy and approach, which are structured to assure that all benefits of simulation are provided to the simulation customer.

# II. SIMULATION TECHNOLOGY AT THE ASC

## A. FACILITIES AND EXPERIENCE

The ASC exists to provide high-quality complex simulations of guided missile systems and related hardware for the defense community. A full range of simulation services is available, including all-digital and hybrid (digital/analog) computer simulation, with particular emphasis on seeker-in-the-loop simulations in which missile seeker hardware is exercised dynamically at its proper electromagnetic operating frequency. This

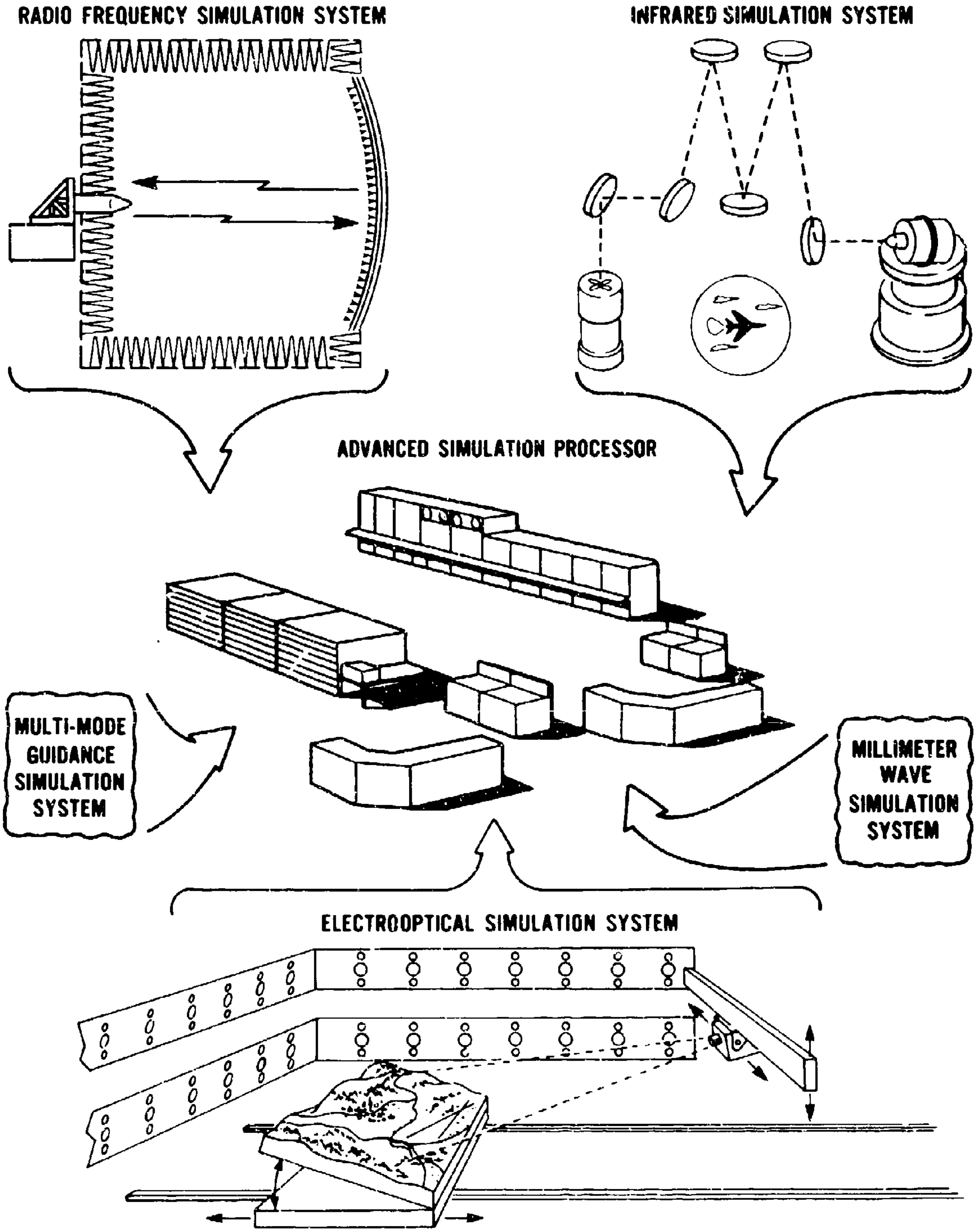


Figure 4. ASC Simulation Facility

emphasis derives from the complex, non-linear characteristics of modern seekers and the complexity of their dynamic interaction with their electromagnetic environment. The seeker-in-the-loop simulation facilities available at the ASC are depicted in Figure 4. Three hardware simulators, the Radio Frequency Simulation System (RFSS), the InfraRed Simulation System (IRSS) and the ElectroOptical Simulation System (EOSS), share a hybrid computer complex, the Advanced Simulation Processor, on which the effects of missile flight dynamics are modeled. Additional hardware simulators for millimeter wave and multi-mode guidance systems are planned. Each hardware simulator consists of four major components: a chamber in which the environmental stimulation of the seeker takes place, a flight table on which seeker hardware is mounted and which produces the dynamic roll, pitch and yaw angular motion which the seeker experiences during flight, a source of electromagnetic energy at the seeker's operating frequency, and the computers and signal generation hardware necessary to control the simulation and the characteristics of the radiated electromagnetic energy. A general overview of a typical simulation configuration in the RFSS is illustrated in Figure 5. An expanded summary of the operational capabilities of the ASC is provided in Subsection C.

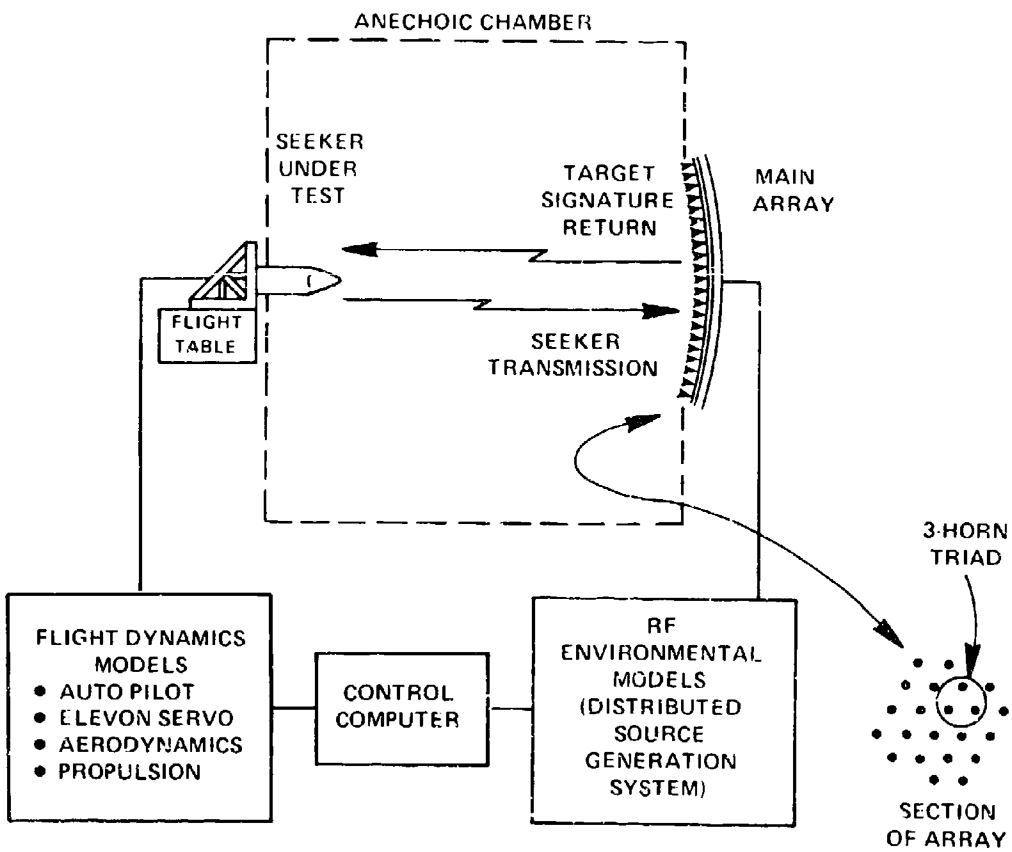


Figure 5. RFSS Simulation Overview

The ASC has provided both computer and seeker-in-the-loop simulation support for a large number of RF, IR, and EO systems. Within the RFSS facility, usage has been close to 100% capacity, with more than 50 major simulations conducted during the first six years of operation. Over 25 separate teams of user engineers have participated. Simulations are funded by the user and are scheduled to accommodate DoD program schedules and priorities; however, priorities have not been a problem.

## B. ASC SIMULATION PHILOSOPHY

The simulation philosophy of the ASC is dominated by three major elements: (1) seeker hardware should be included in the simulation; (2) environmental models are critical for seeker-in-the-loop simulation realism; and (3) user participation is required for a successful simulation. Figure 6 illustrates the three major components in the assessment of missile performance. The computer modeling of the flight dynamics system, including missile components and their aerodynamic interaction with the atmosphere, is a relatively mature discipline which can be accomplished with adequate fidelity provided that established engineering techniques are properly employed. The seeker system, which provides guidance information to the flight dynamics system, is generally a complex non-linear device which is difficult to describe mathematically, as is its interaction with the third element, the electromagnetic environment which stimulates seeker response. Verification and validation of the overall simulation requires as a prerequisite that each of the three major simulation elements be verified and validated.

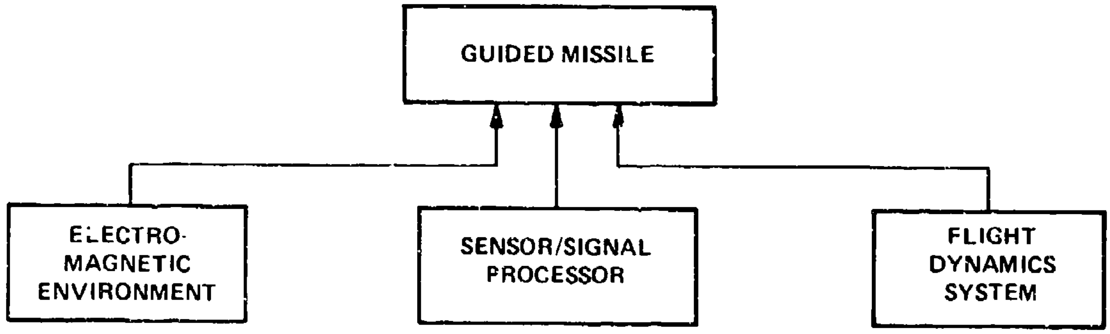


Figure 6. Major Missile Performance Elements

In the ASC, realistic flight dynamics models are provided in the Advanced Simulation Processor, and uncertainties associated with seeker modeling are avoided by utilizing seeker hardware in the simulation. The flight dynamics models are implemented through a step-by-step integration of previously verified submodules until a completely verified model is assembled. It is then validated by comparing a time history of deflection commands to the missile control surfaces generated by the model with corresponding signals telemetered from actual flight tests or generated by a previously validated simulation model. The electromagnetic environment is thus the critical element in achieving seeker-in-the-loop simulation realism. Great emphasis is placed in the ASC on the development, verified implementation, and validation of environmental models using independent measurements and flight test data. These models are developed in hierarchies of complexity, ranging from very simple to highly sophisticated. The selection of the appropriate models for an individual simulation program depends upon the application and sensitivities of the particular seeker under test. Model hierarchies allow the selection of the appropriate level of environmental complexity for each seeker, and permit the determination of seeker sensitivity to elements of the environment through systematic variation of model parameters.

Customer participation is an essential factor in the success of simulations at the ASC. As a member of the simulation team, the customer provides managerial insight and technical information for the system being simulated. He also must contribute to simulation planning by helping to define simulation goals and objectives, and the use to be made of simulation results. Detailed seeker operation and simulation goals and objectives are key factors in selecting the appropriate level of environmental model complexity. As illustrated in Figure 7, the selection of models more complex than is suitable for the intended scenario or application results in more time and cost than is required, while overly simple models result in simulation predictions which do not address the critical issues and encourage misapplication of results. The achievement of a cost-effective simulation whose results can be used with great confidence requires the level of environmental complexity appropriate for the scenario and application at hand.

The use which will be made of simulation results in the customer's decision-making process also is essential in determining the scope of the validation program which is appropriate for his simulation. When critical issues are to be decided based upon simulation data, it is essential that the validity of this data be evaluated, for only then can the decision maker place the proper level of confidence in the simulation results. Validation of both the environmental models and the overall simulation requires a commitment by the customer to provide the necessary independent data and the resources to perform the validation assessments.

The ASC technical approach to environmental modeling and the verification and validation of these models is the subject of Section III.

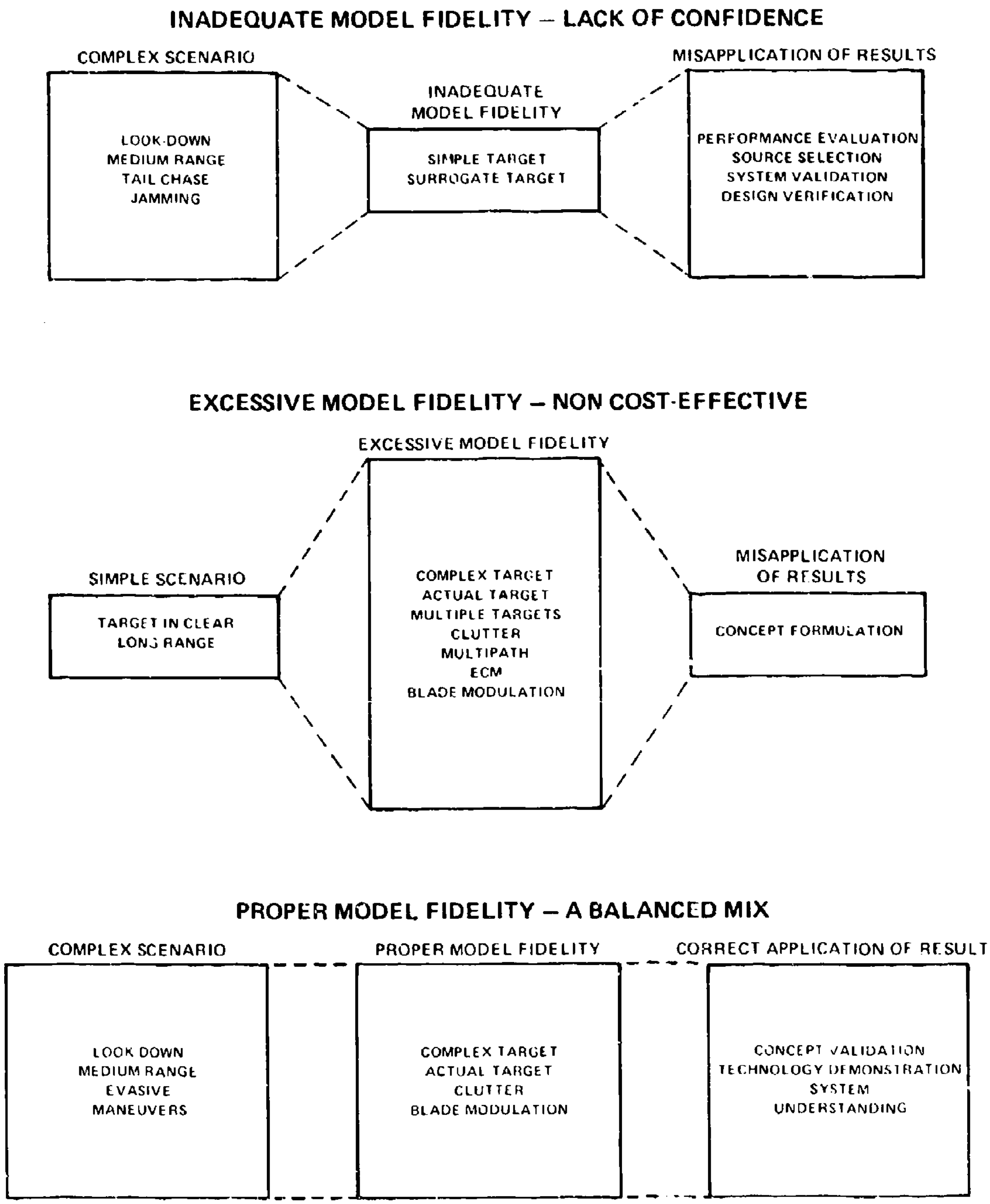


Figure 7. Selection of Proper Model Fidelity

## C. ASC SIMULATION CAPABILITIES

Development of the Advanced Simulation Center capability was initiated in the late 1960's in response to a MICOM mission requirement for an Army-wide source of expertise and capabilities in large-scale seeker-in-the-loop simulations. Since activation in 1975 the ASC has developed over 150 large-scale all-digital, hybrid, seeker-in-the-loop, and man-in-the-loop system simulations. The primary user has been MICOM, but users have included many other Army, Navy, and Air Force organizations. Simulations are accomplished by single or combined use of the Advanced Simulation Processor Complex, the InfraRed Simulation System, the ElectroOptical Simulation System, and the Radio Frequency Simulation System in a real-time dynamic environment. A summary of ASC simulation capabilities is given in Figure 8.

| PARAMETER | IRSS | EOSS | RFSS |
|---|---|---|---|
| WAVELENGTHS | 0.2 TO 0.4$\mu$, 1 TO 5$\mu$ | VISUAL, 2 TO 14$\mu$ ULTRAVIOLET | 1.7 TO 15 CM |
| MAX SEEKER DIAMETER | 10 INCH | 14 INCH | 16 INCH |
| MAX SEEKER WEIGHT | 25 LBS | 150 LBS | 150 LBS |
| FLIGHT TABLE FREQUENCY RESPONSE | 15 TO 22 Hz | 10 TO 23 Hz | 13 TO 30 Hz |
| PHYSICAL EFFECTS SIMULATOR SIZE | 27 X 12 X 16 FT (HIGH, WIDE, LONG) | CHAMBER: 38 X 40 X 120 FT (HIGH, WIDE, LONG) PLUS 240 FT OUTDOOR EXTENSION | CHAMBER: 48 X 48 X 40 FT (HIGH, WIDE, LONG) |
| TARGET RANGE | 160 TO 16,000 FT | 1,500 TO 144,000 FT | 400 FT TO 94,000 FT (ACTIVE COHERENT)<br>40 FT TO MISSILE SENSITIVITY (OTHER) |
| MAX CLOSING VELOCITY | 4,900 FT/SEC | 9,000 FT/SEC | 8,000 FT/SEC (ACTIVE COHERENT)<br>20,000 FT/SEC (OTHER) |
| MAX TARGET ANGULAR RATE | 100°/SEC | 200°/SEC | 21,000°/SEC |
| TARGET DYNAMIC RANGE | $3.6 \times 10^4$ TO $3.6 \times 10^2$ W/cm$^2$ sr | $10^4$ TO $10^3$ FT CANDLES | MISSILE SENSITIVITY to 17 dBm/m$^2$ |
| UPDATE RATE | 1 TO 2 MSEC | ANALOG | 1 TO 5 MSEC |
| FIELD OF VIEW | ·90° Az, ·30° El | 120° p, ·40° y | 42° CONICAL SECTOR |
| TARGET/CLUTTER TYPES | TAILPIPE/FLARE<br>PLUME<br>FUSELAGE<br>BACKGROUND<br>COUNTERMEASURES | GROUND TARGETS<br>TERRAIN<br>THERMAL TERRAIN | GROUND RADAR<br>AIRBORNE TARGETS<br>CLUTTER<br>ECM<br>MULTIPATH<br>JET ENGINE MODULATION<br>RF IMAGING |

Figure 8. ASC Capabilities Summary

The Advanced Simulation Processor Complex provides high-speed, large-memory processors to support hardware-in-the-loop simulations within the complex and seeker-in-the-loop simulations in the IRSS, EOSS, and RFSS; to simulate large systems in all-digital or hybrid representation; and to conduct research on advanced processors. The Advanced Simulation Processor Complex consists of large-scale digital and analog processors with capabilities of 500 million to one billion operations per second; a separate test bed for advanced processor research; direct digital and analog data links to the EO, IR, and RF simulators; and a highly effective

special-design Interconnection and Setup Subsystem. An advanced software operating system integrates the real-time digital processor, hybrid compiler, vector processors, high-speed multivariant function generators, hardware and software interfaces, and the high-level simulation language required for seeker-in-the-loop system simulation.

The InfraRed Simulation System provides a simulation tool for the design, development, and evaluation of infrared sensor systems applicable to surface-to-air, air-to-air, and air-to-surface missiles. Sensors in the 0.2 to 0.4 and 1.0 to 5.0 micron bands are hybrid computer controlled in six degrees-of-freedom during the target engagement sequence. A gimballed flight table provides pitch, yaw, and roll movements to the sensor airframe. A target generator simulates a variety of target/background combinations which include tailpipes, plumes, flares, and fuselages in single or multiple displays against overcast or clear skies under various lighting conditions. These are displayed in azimuth, elevation, and range at the proper aspect by the target projection subsystem through a folded optical network, a display arm, and a display mirror. Simulation capability ranges from open-loop component evaluation to closed-loop total system simulation with countermeasures.

The ElectroOptical Simulation System provides realistic and precisely controlled environments for the non-destructive simulation of a wide variety of ultraviolet, visible, and near-infrared sensor systems. Actual sensors are hybrid computer controlled in six degrees-of-freedom while viewing targets under controlled illumination levels in an indoor simulation chamber and under ambient conditions on an outdoor simulation range. Three-dimensional target simulation is provided on a 32- x 32-ft terrain/target model/transporter which features a variety of topographical and man-made complexes at 600:1 and 300:1 scales, removable model sections, and fixed and moving targets. A moving projection subsystem provides two-dimensional representation. A gimballed flight table which provides pitch, yaw, and roll movements to the sensor airframe is attached to a transport which moves vertically and laterally. The terrain/target model or the two-dimensional projection subsystem is moved toward the flight table to provide the sixth degree-of-freedom. An adjacent high-resolution TV/joystick console and helicopter crew station provide a means of evaluating man-in-the-loop guidance and target acquisition concepts. The EOSS also has a thermal terrain model which accommodates the infrared spectral region of 2 to 14 microns.

The Radio Frequency Simulation System provides launch to intercept seeker-in-the-loop simulation of passive, semiactive, coherent and non-coherent active, command, beam rider, imaging, and track-via-missile missile systems in surface-to-air, air-to-air, air-to-surface, and surface-to-surface engagements. Engagement scenarios include the use of multiple targets and jamming signals generated by actual jammers in the loop and the simulation of distributed clutter, targets distributed in range and angle, multipath, glint, and scintillation phenomena. Simulation in the RFSS is

accomplished by radiating at operating wavelengths within a shielded anechoic chamber to a hardware seeker functioning in a dynamically simulated missile-target engagement. The electromagnetic environment for the seeker signal processor is simulated by means of a computer controlled RF signal generation system which feeds RF signals to the target and ECM antenna arrays. The targets, controllable in time, space, frequency, amplitude, polarization, phase, and number, are presented on a 534-element array of antennas representing a 42° field of view. Up to four independent targets can be generated and displayed simultaneously in the 2- to 18-GHz range. By means of coaxial cable and wave guide paths between the RF Signal Generation System and the guidance sensor, simulated downlink, uplink, and fuzing signals may be passed between the guidance sensor and the RF Generation System. In addition to the target antenna array, two denial electronic countermeasures channels feed 16 ECM antennas distributed among the target antennas to display up to two ECM signals for simulating standoff jammers. ECM signals, generated by actual jammers or emulated with an RF generation channel, can be dynamically co-located on the target signal through the use of a separate target channel to simulate an on-board self-screening or deceptive jammer. Ejectable and escort screening jammers can be simulated in a similar manner with separate dynamic trajectory control. The missile-target relative motion is accomplished by controlling the target return signal in angle and range and by seeker angular motion provided by the flight table.

In addition to the ASC laboratory facilities, two other elements contribute to the ASC simulation capability: the extensive software programs now available at the ASC and the ASC experienced technical staff. Some 250 special-purpose software programs and techniques now exist at the ASC. About one-fourth were developed prior to activation; the remainder evolved over six to eight years of simulation operation as simulation experience increased and new equipment and capability were added. These programs provide laboratory control of standard functions such as target motion; calibration such as flight table readiness tests; diagnostics such as for the master/minicomputer interface; simulation aids such as real-time graphics; and simulation dependent software such as executive control, missile model, and environmental models.

Simulation development, operations, maintenance, and system improvements at the ASC are handled by a technical staff of over 100 engineers and technicians composed of Government and support contractor personnel. The principal engineering discipline is electronic engineering. The ASC technical staff was developed over the past six to eight years by careful selection and, as it now exists, is a national resource in seeker-in-the-loop simulation.

Planned expansion of the ASC includes adding imaging infrared, multimode, millimeter, and additional RF capabilities. Seeker-in-the-loop simulators for imaging infrared, multi-mode, and millimeter wave weapon systems are scheduled for activation in FY 86/87. Prior to that time, an

interim millimeter facility will be provided by modifying the EOSS without impairing the electrooptical capability.

## D. SIMULATION MANAGEMENT

A successful simulation requires that the customer and ASC have a common definition of and agreement on simulation goals, objectives, and requirements. It is important that the customer understands what equipment and personnel he will provide and how they will interface with ASC counterparts. It is particularly important that the user be clearly aware of how the simulation data and results will be used to make management decisions and to resolve technical issues.

A typical ASC simulation program is conducted in five phases as shown in Figure 9.

The *Coordination and Planning* phase of the simulation usually starts through an initial contact between the potential customer and the manager of the facility to be used. At this meeting, the potential customer should be prepared to discuss the following:

- Simulation goals and benefits,
- Technical characteristics and requirements,
- Simulation scenario requirements, and
- Use of simulation results.

These requirements are then reviewed against the capability of the ASC to perform the simulation. Schedule requirements are discussed and an initial cost estimate is made. The simulation program is subsequently refined by preparation of a *Simulation Task Description* (what is to be done) and an *Accomplishment Plan* (how it will be done). The Coordination and Planning phase ends with a Statement of Work and a negotiated agreement.

The *Simulation Development* phase typically requires from three to twelve months, depending on the size and complexity of the simulation. Development time can be as short as one to two weeks if a previously developed simulation can be used. During this phase, the environmental models, simulation scenarios, software, environmental model implementation and generation, interface controls, recording setup, display setup, and digital and/or hybrid missile models are developed. Simulation planning is finalized by the issue of a *Simulation Test Plan* and a *Simulation Test Procedure*. Design and fabrication of new interfaces are usually accomplished by the ASC.

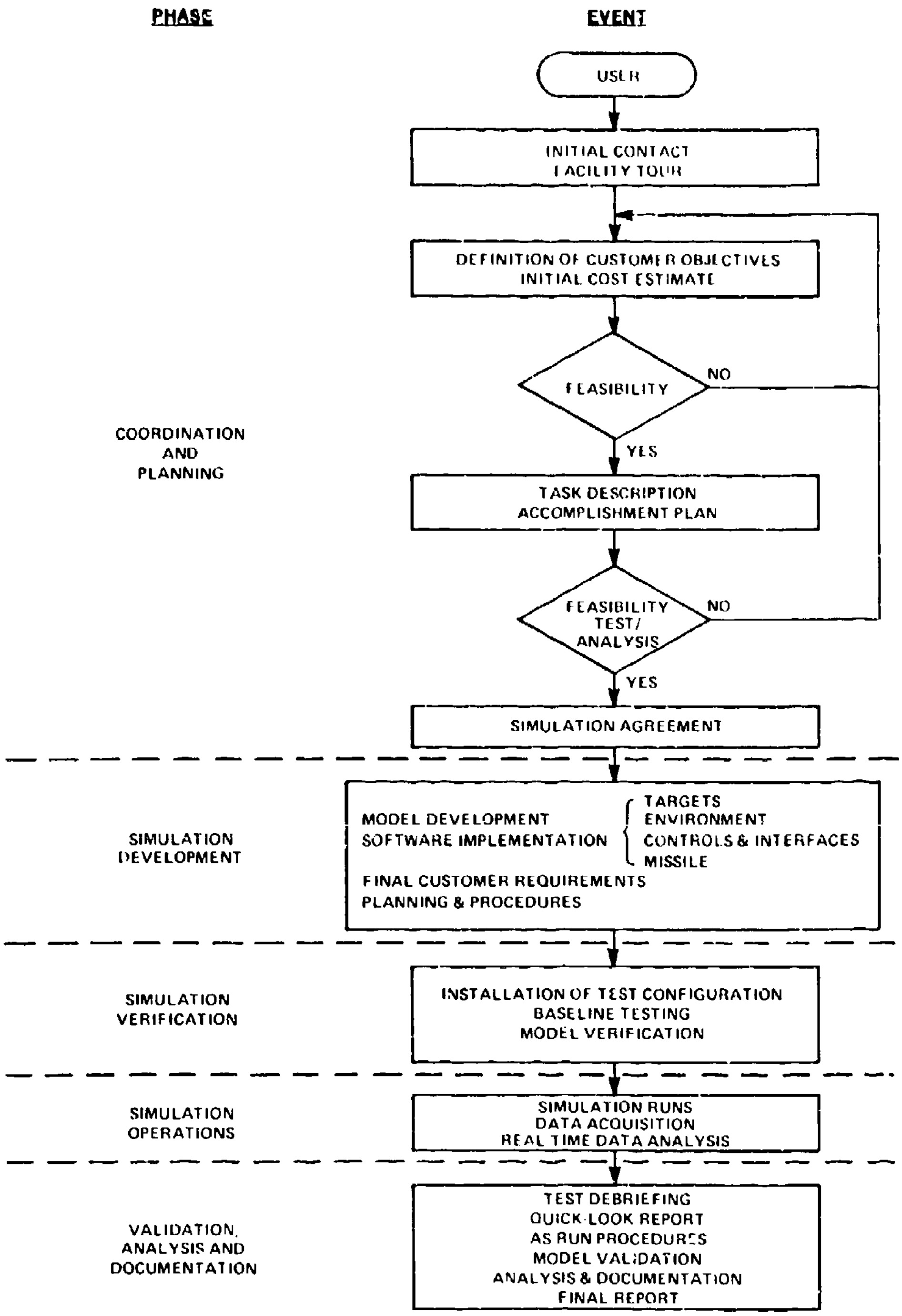


Figure 9. Typical ASC Simulation Program

The *Simulation Verification* phase integrates the facility simulation configuration with the hardware and support equipment provided by the user. The user hardware is integrated with the facility using the missile/facility interface and control panels provided by joint ASC/user design. The operational readiness of all software is verified, and baseline verification tests are performed, culminating in measurements of the propagated electromagnetic signal using both a test receiver and the seeker-under-test. Finally, the missile guidance loop is closed by a standard procedure in which software modules are replaced systematically by hardware elements and the overall simulation is verified.

The *Simulation Operations* phase begins with residual open-loop testing of the seeker. Periodic baseline tests are performed. Once the loop is closed, sets of 5 to 50 runs are typically performed for 25 to 100 engagement scenarios. Total runs for an average program vary from 1000 to 3000, with the number of runs conducted for a given program being determined by user requirements. The length of the Simulation Operations phase is usually estimated on the basis of a daily average of 50 to 100 runs, based on the experience of more than 50 major simulations conducted to date.

The *Validation, Analysis and Documentation* phase accomplishes data collection, validation, reproduction, and distribution. A formal debriefing and an analysis or final report are prepared. Levels of analysis and documentation are determined by agreement between the ASC and the customer. Standard documentation is a data report and the *As-Run Test Procedures*.

## III. ENVIRONMENTAL MODELING

### A. MODELING PHILOSOPHY

A general methodology for environmental model development has evolved at the ASC. Models for specific features of the environment are developed in hierarchies of complexity and realism. The structure of the hierarchy ranges from a simple and straightforward representation of a particular phenomenon through a gradual increase in complexity to the most sophisticated representation of an environment. This approach allows parametric analysis of the sensitivity of a given seeker to specific features of the environment. For example, the glint reduction capabilities of an RF seeker can be evaluated by first ascertaining performance against a non-glinting target and then successively adding glint of varying severity to see how performance is affected. The selection of the appropriate level of complexity is based upon the goals and objectives of the customer and anticipated benefits.

It is also crucial that the realism of the simulation be evaluated by comparison with independent data. The credibility of the overall

simulation hinges on the realism of the environment. Great emphasis is placed in the ASC on the realism of the environment presented to the seeker under test. Specific examples of the environmental models and the verification and validation program developed for use in the RFSS are presented in the following subsections.

## B. RF ENVIRONMENTAL MODELS

Because of their advanced state of development, the environmental effects models used in the RFSS are a particularly good example of the implementation of the ASC modeling philosophy, methodology, and approach. The environment of an RF missile seeker includes radar returns from the desired target, other aircraft and airborne material, the earth's surface, and ECM emissions. These signals may be characterized in terms of their amplitude and phase spectra, time-of-arrival, direction-of-arrival, frequency, polarization, and number. Because of the complexity of the signals, an exact duplication of the real-world RF environment in seeker-in-the-loop simulations is clearly not possible. The objective of the RFSS environmental modeling effort is to ensure that the seeker is stimulated with signals which induce the same missile response as in an actual engagement. Modeling requirements are directly related to the seeker resolution in range, angle, power and doppler, the engagement scenario, and the intelligence of the seeker processor.

A wide variety of scenarios can be simulated in the RFSS by combining models of different levels of complexities from the available hierarchies. Hierarchies have been developed for targets, clutter, and blade modulation models. These models can accept various parameters to represent particular aircraft, specific jet engines, and empirical clutter data. For example, the target model hierarchy has four levels:

I. Isotropic Scatterer Model

II. Empirical Scatterer Model

III. Empirical Statistical Model

IV. Deterministic Multiple Scatterer Model

The simplest, the Isotropic Scatterer Model, consists of a point reflector located in space at the target centroid with a fixed radar cross-section (RCS). The Empirical Scatterer Model allows for slow variation with aspect angle of both the target RCS (amplitude scintillation) and apparent angular position (low-frequency glint or bright-spot-wander). The Statistical Model adds to the Empirical Model high-frequency amplitude scintillation (rapid variation with aspect angle) and angular glint components which may be either aspect or aspect-rate dependent. Typical variation of the RCS with aspect angle in the wings plane of the target for each of these three model types is illustrated in Figure 10. The final and most realistic member of the hierarchy, the Deterministic Multiple Scatterer Model, treats

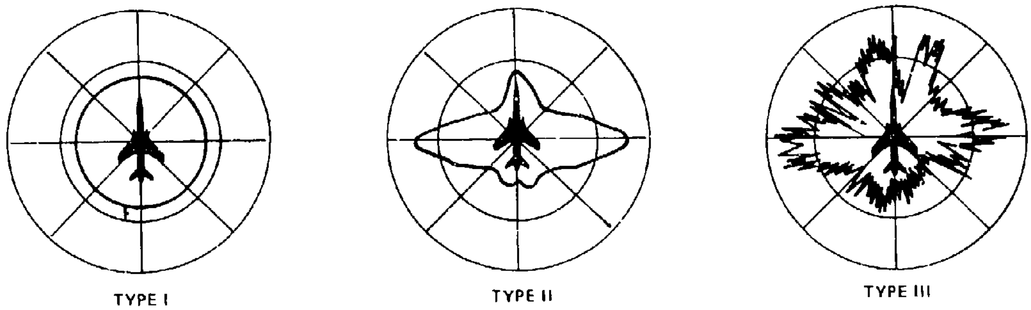


Figure 10. Variation of RCS with Aspect Angle for Different Model Types

the target as a collection of point scatterers (Figure 11). Each scatterer can have aspect-dependent amplitude and phase scattering properties with the total target return computed as the coherent superposition of the returns from the individual scatterers illuminated by the radar transmitter. This results in presentation to the seeker of realistic amplitude scintillation and range and angle glint.

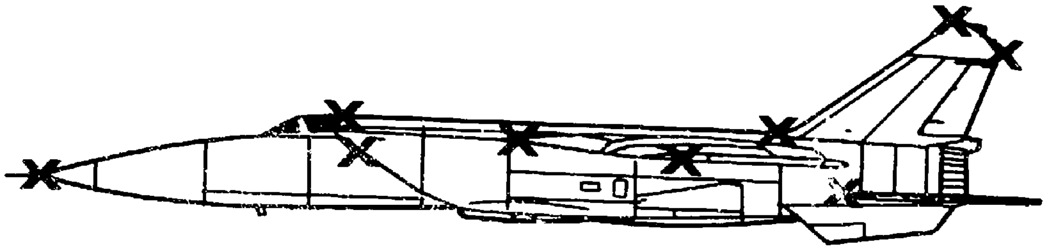

Figure 11. Representation of Target by Scattering Centers in Deterministic Multiple Scatterer Model

The selection of specific models appropriate for a given scenario is based upon two factors: (1) seeker performance characteristics and (2) the hardware available in the RFSS to implement these models. Because RFSS environmental model resources are limited, presen...ion of simultaneous complex environmental features can best be accomplished by dividing the missile flight into guidance phases such as acquisition, track, and terminal homing. The environmental effects which are critical during each of these phases are then identified. This permits the allocation of RFSS resources to those elements of the RF environment which are most significant to missile performance in that particular phase. It is unnecessary, for example, to simulate difference channel clutter when testing acquisition performance of a monopulse seeker.

Seeker-in-the-loop simulation offers an ideal test bed for testing potential or actual ECM techniques. Using the RFSS multiple target capability, a wide variety of jamming signals can be simulated, from brute-force noise jamming to intelligent, repeater jamming. Actual ECM hardware is preferred and normally used; however, models of jammer techniques are available. The purpose of the simulation may be to evaluate seeker ECCM capabilities, or to develop ECM techniques against a threat-representative seeker. In either case, the ASC provides covert operation not available on a flight test range.

## C. ENVIRONMENTAL MODEL VERIFICATION AND VALIDATION

To ensure that simulation data produced in the ASC can be used by decision makers with confidence and in the proper context, environmental model verification and validation (V&V) is an essential ingredient in a simulation program. As discussed in Subsection B, environmental models are the forcing functions in determining seeker-in-the-loop simulation realism, and their validation is a prerequisite to the validation of the overall simulation. As applied to RF Environmental Models utilized in HWIL simulation in the RFSS, the following definitions are appropriate:

- Verification--the process involving acquisition and analysis of RFSS measurement data which ensures that RF Environmental Models implemented in the RFSS meet their design objectives.

- Validation--the assessment and quantification of the degree to which RF Environmental Models are adequate representations of physical reality.

The V&V process is directly related to the manner in which models are developed and implemented in the RFSS. Initially, a mathematical representation of the physical effect is developed. This math model is typically a non-real-time FORTRAN computer program derived from an empirical or analytical data base (Figure 12). The first step in verification is to demonstrate that this model adequately reproduces the data set upon which it is based. The math model may also be validated by comparison with independent test data.

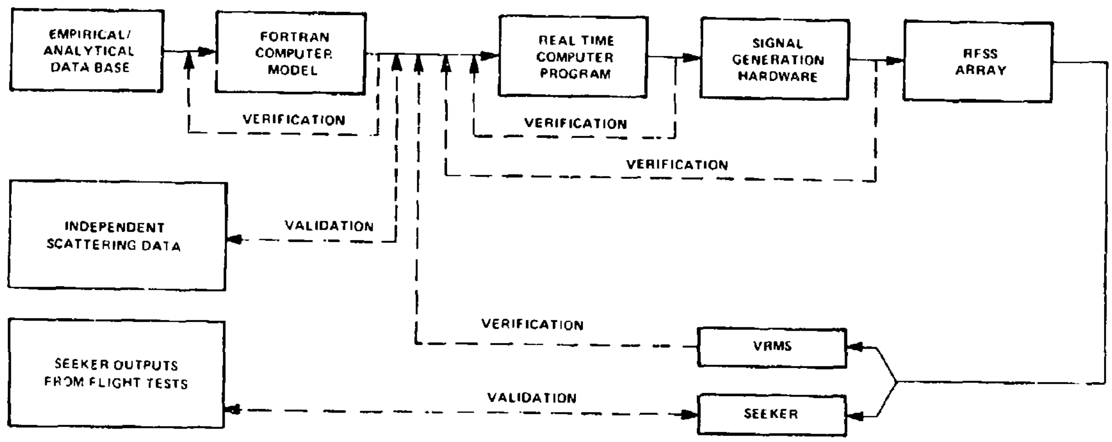


Figure 12. Verification and Validation of RF Environmental Models

Because seeker-in-the-loop simulation requires that the seeker be stimulated dynamically at its operating frequency in a real-time, time-critical environment, the math model must be converted into a "real-time" computer program which produces the commands necessary to modulate the radiated RF signature. Verification measurements are made at various nodes in this signal generation process and the data compared with corresponding outputs from the math model. Finally, the RFSS Verification Receiver Measurement System (VRMS) is used to assure that the propagated waveforms received at the seeker aperture correspond to the intended math model representations.

Environmental model validation is achieved by comparing seeker outputs generated during RFSS simulation runs with corresponding seeker outputs from flight tests. These validation comparisons are designed to quantitatively establish the degree of model realism and to define the regions and limitations of model validity. This information permits the decision maker to utilize simulation predictions in a more intelligent, better informed manner.

The validation process, as illustrated in Figure 13, can be viewed as building a pyramid of confidence in weapon system performance predictions. As new scenarios are introduced, sensitivity analyses performed, models improved, and simulation predictions validated with flight test data and other independent analyses, the knowledge base of the pyramid is

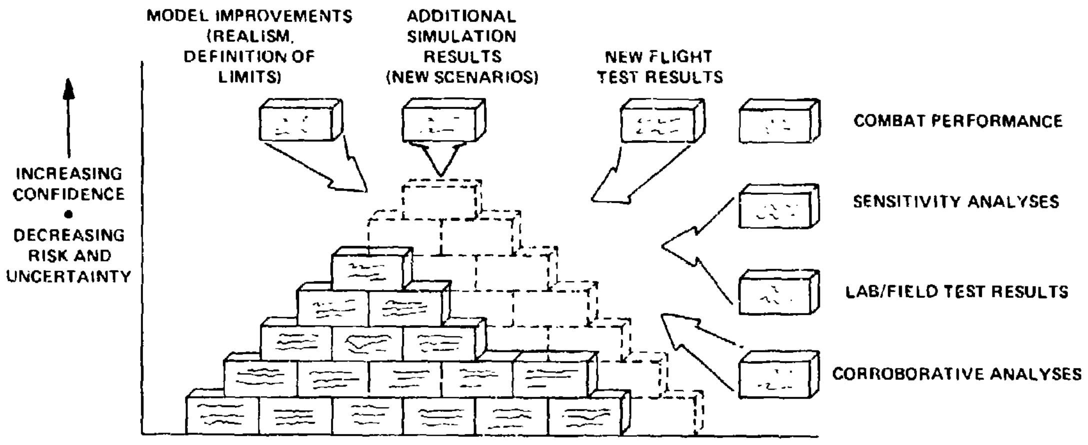


Figure 13. Validation - Building a Pyramid of Confidence

broadened and higher levels of confidence reached over a period of time. With simulation results supported by a carefully structured V&V foundation, engineers and program managers are able to make difficult missile system development decisions with increased confidence and decreased risk.

Validation cannot be achieved through a single experiment or flight test. Each input to the validation process generates new insight into system performance. As deficiencies are corrected and results corroborate and support each other, confidence is developed in predicting performance. Total confidence can never be achieved because not all possible scenarios and contingencies can be explored in validation testing, but an iterative validation program carried out over a period of time will reduce risk and uncertainty.

## IV. SUMMARY

Simulation plays an important role over the entire missile system life cycle when properly integrated with other methods of system evaluation. The experience of the ASC in providing high-quality complex

simulation services to the defense community has demonstrated the importance of the following key simulation elements:

- Simulation realism is achieved by utilizing seeker and guidance electronics hardware in the simulation.

- Environmental models are crucial in achieving realistic seeker-in-the-loop missile guidance simulations.

- Models of the proper level of complexity must be selected based upon simulation objectives and seeker sophistication.

- Verification and validation of both environmental models and the simulation are necessary for confident use of simulation results.

- Customer participation in defining goals, objectives, and requirements is essential to achieve a successful simulation.

- A simulation support program should evolve in conjunction with the missile system development program. Complexity is added as required, resulting in a mature simulation with the proper fidelity to support the fielded system.

- Key benefits of such a simulation support program encompass both management savings in resources and technical contributions to system understanding and effectiveness.

Simulation provides management control through measurement and evaluation of performance and results in improved decision-making.

The following documentation is available for more detail on ASC capabilities and operational procedures:

1. *Radio Frequency Simulation System (RFSS) Users Guide*, RFSS-003-8, U.S. Army Missile Command, May 1979.

2. *Radio Frequency Simulation System (RFSS) Capabilities Summary*, Technical Report TD-77-08, U.S. Army Missile Command, April 1977.

3. *Verification and Validation of RF Environmental Models - Methodology Overview*, Technical Report RD-81-2, U.S. Army Missile Command, October 1980.

4. *RF Environmental Modeling in the Radio Frequency Simulation System*, Technical Report CR-81-3, U.S. Army Missile Command, May 1981.

5. *The Advanced Simulation Center Brochure*, U.S. Army Missile Command.

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